DOE/ID-12114

DOE/ID-12114

JOHN IRVING

Guidelines for Revegetation of Disturbed Sites at the Idaho National Engineering Laboratory

Jay E. Anderson
and Mark L. Shumar

June 1989

D. Harding 5-17-92

Idaho National Engineering Laboratory
U.S. Department of Energy • Idaho Operations Office

DISCLAIMER

DOE/ID-12114

Guidelines for Revegetation of Disturbed Sites at the Idaho National Engineering Laboratory

Jay E. Anderson and Mark L. Shumar
Department of Biological Sciences
Idaho State University

June 1989

Radiological and Environmental Sciences Laboratory
U.S. Department of Energy
785 DOE Place
Idaho Falls, ID 83402

Table of Contents

Table of Contents (cont.)

Tables and Figures

PREFACE

The Idaho National Engineering Laboratory (INEL), a leading center for nuclear safety research, nuclear waste technology, and advanced energy concept development, occupies 890 square miles of the upper Snake River Plain in southeastern Idaho. Establishment of this center for nuclear research in 1950 resulted in protection of a large expanse of natural sagebrush cold desert. In 1975, the INEL was designated as a National Environmental Research Park, a field laboratory set aside for ecological research and for study of the environmental impacts of energy development. Today, the INEL supports a diversity of wildlife and a rich natural flora. The area is recognized as an important reservoir of the genetic diversity of sagebrush steppe ecosystems.

The arid climate of the INEL presents a serious challenge for the reclamation of disturbed sites. Because of limited precipitation and a short growing season, disturbed areas "heal" slowly. Timely and effective revegetation of such sites is necessary to stabilize soil and prevent erosion, preclude colonization by undesirable weeds, and maintain an aesthetically-pleasing landscape. This guide ~~was developed~~ to aid in such revegetation efforts.

Planning for reclamation prior to initiating construction or development activities can minimize the areal extent and severity of disturbances and reduce costs associated with reclamation. Suggestions for defining objectives for reclamation projects and examples of specific objectives for revegetation planning at the INEL are provided. Because meeting some objectives in the most expedient manner may preclude or delay meeting others, implications and tradeoffs of various revegetation strategies are discussed.

The success of a revegetation project depends on selecting species that are adapted to the soils and climate of the INEL. Characteristics of plant species recommended for revegetation projects are presented. Specific recommendations of seeding mixtures for restoring natural communities, seeding waste management sites and roadsides, and establishing strips of fire-resistant vegetation are included. Techniques for preparing seedbeds, seeding, and transplanting are discussed. Timing of planting is critical at the INEL and specific recommendations are given. Finally, we provide guidelines for evaluating the success of revegetation projects.

ACKNOWLEDGMENTS

This publication is a contribution from the Idaho National Engineering Laboratory Ecological Studies Program, supported by the Office of Health and Environmental Research and the Division of Waste Products, U.S. Department of Energy, through the Idaho Operations Office. Seeds for the experimental garden and various revegetation projects were provided by the Soil Conservation Service Plant Materials Center at Aberdeen, Idaho, and the Forestry Sciences Laboratory in Boise. Steve Monsen, Gary Davis, Chuck Howard, Jacy Gibbs, and Gary Young provided technical advice. Diane and Julie Pavek, Guy Marlette, Ron Waschmann, and numerous Associated Western University Fellows assisted with field work. Mike Pellant and Roger Rosentreter provided suggestions and Bureau of Land Management publications on revegetation and greenstripping. Tim Reynolds and O.D. Markham provided technical support and comments on the manuscript. We are especially grateful to Nancy Shaw and Steve Monsen for their thorough reviews of a draft of these guidelines and their detailed suggestions for revisions. Richard Inouye produced the camera-ready copy.

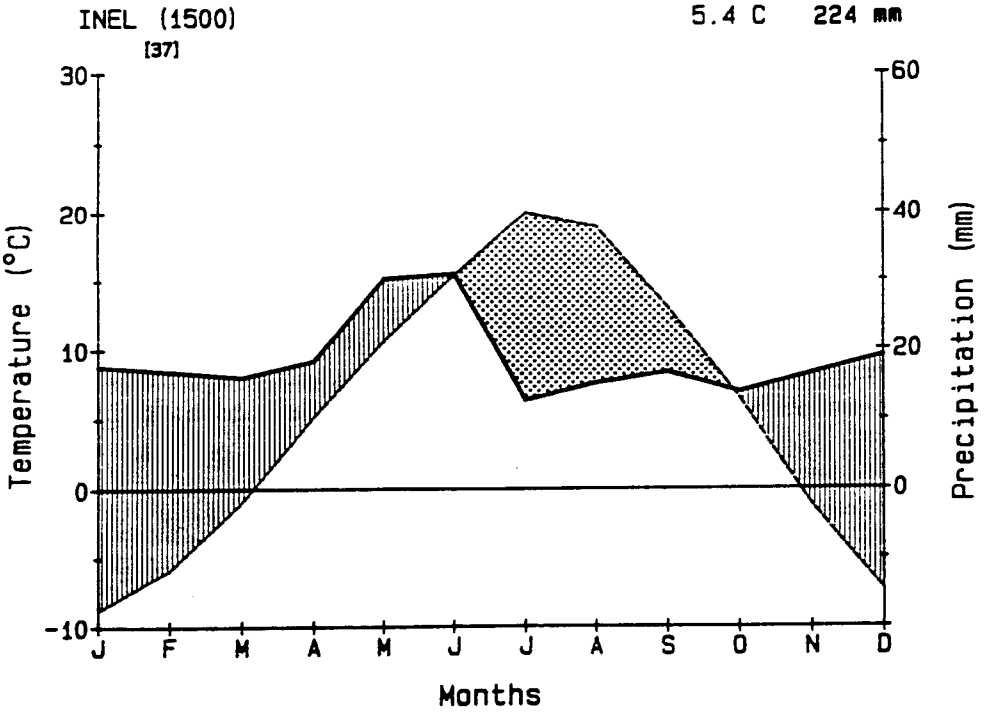
INTRODUCTION

Climate

The Idaho National Engineering Laboratory (INEL) occupies 2315 km^2 (894 square miles) of the temperate sagebrush-steppe region (West 1983) on the upper Snake River Plain in southeastern Idaho. The climate of this area is semiarid and distinctly continental, with large daily and seasonal temperature fluctuations. During summer, low humidities and clear skies result in high temperatures and high evaporative demand during the day and rapid radiation cooling resulting in low temperatures at night. Winters are cold, with 2 - 3 months having mean temperatures below freezing (Figure 1). Topsoils usually remain frozen from mid to late November through mid February or early March. Snow cover typically persists for two to three months or more. The average annual temperature is 5.4 C (41.7 F), and the frost free period is about 90 days.

Most of the precipitation received at the INEL is derived from air masses moving off the Pacific Ocean. The INEL, at an average elevation of about 1500 m (5000 ft), lies in the rain shadow of the numerous mountain ranges of central Idaho. Mean annual precipitation is 224 mm (8.8 in). On the average, precipitation exceeds evaporation from October through May (Figure 1, vertical hatching) and evaporation exceeds precipitation from June through September (Figure 1, stippled area). As a consequence, melting snow and spring rains account for virtually all of the annual recharge of moisture in the soil profile (Anderson et al. 1987). Many plants initiate growth in late

Figure 1. Climate diagram (*sensu* Walter *et al.* 1975) for the Idaho National Engineering Laboratory, Idaho, based on data for 37 years from the Central Facilities Area (NOAA, unpublished data).



March or early April and grow rapidly through early June; by the end of June, a large portion of the stored soil moisture is typically used (ibid.). Summers are very dry, and precipitation from summer storms wets only the top few centimeters of the soil profile (Caldwell 1985). Many grasses and forbs complete their cycle of growth and become quiescent by late June or July; other perennials such as sagebrush and rabbitbrush continue to grow slowly and bloom in late summer or fall.

The predictability of the annual cycle of moisture availability and the coincidence of moisture availability and favorable temperatures for plant growth in the spring are important factors to consider when planning revegetation efforts. The implications of these climatic characteristics for planting schedules are discussed in the section "When to Plant."

Natural Vegetation

Vegetation Types

Plant communities are not discrete entities; typically, species composition changes gradually across the landscape as species respond individually and differentially to changing environmental conditions. Consequently, vegetation types intergrade continuously, producing a diverse array of communities. Abrupt transitions are sometimes found where environmental conditions change rapidly. The Great Basin wildrye communities found in depressions where deep soils have accumulated are an example. We recognize five major vegetation types at the INEL; most of the common species of plants are found in several types (Table 1). Each major type is discussed briefly below.

Big Sagebrush Steppe

Most of the natural vegetation at the INEL consists of a shrub overstory with an understory of perennial grasses and forbs. The most common shrub is Wyoming big sagebrush (*Artemisia tridentata* subspecies *wyomingensis*). Basin big sagebrush (*A. tridentata* subspecies *tridentata*) may be dominant, or co-dominant with Wyoming big sagebrush, on sites having deep soils or sand accumulation (Shumar and Anderson 1986a). Communities dominated by big sagebrush occupy most of the central portions of the INEL. Green rabbitbrush (*Chrysothamnus viscidiflorus*) is the next most abundant shrub in many of these communities. Other common shrubs are shown in Table 1. Steppe communities dominated by black sagebrush (*Artemisia nova*) or low sagebrush (*Artemisia arbuscula*) occur in isolated areas where soils are very shallow.

At the lowest elevations, the most abundant grass is thick-spiked wheatgrass (*Agropyron dasystachyum*). Bottlebrush squirreltail (*Sitanion hystrix*) is also very common and is the dominant grass in many communities west of Lincoln Boulevard north of the Naval Reactor Facility. Bluebunch wheatgrass (*Agropyron spicatum*) is rare at the lowest elevations on the central portion of the INEL, but it is common at slightly higher elevations to the southwest and along the eastern side, and especially on alluvial fans and the slopes of the buttes. These areas probably receive more precipitation than do areas at the lower elevations. Indian ricegrass (*Oryzopsis hymenoides*) and needle-and-thread (*Stipa comata*) are common throughout, and may be a dominant species on sandy sites. Patches of creeping wildrye (*Elymus triticoides*) are locally abundant.

Compared to much of the sagebrush steppe region (West 1983), which has a long history of livestock grazing, the INEL sup-

Table 1. Relative abundances of common species found in major vegetation types at the Idaho National Engineering Laboratory (+++ = dominant; ++ = common; + = often present, but not common). Absence of a '+' does not necessarily indicate that the species does not occur in that type. See Appendix for common names. Nomenclature follows Hitch cock and Cronquist (1973).

	Sagebrush Steppe	Winterfat/ Saltbush	Great Basin Wildrye	Threetip Sagebrush	Utah Juniper
Shrubs and Trees:					
Juniperus osteosperma					+++
Artemisia tridentata	+++	+	++	+	+
Artemisia tripartita	+			+++	++
Atriplex confertifoliaa		++			
Atriplex nuttallii	+	++			
Atriplex spinosa	+	++			
Ceratoides lanata	++	+++			
Chrysothamnus nauseosus	+		+		
Chrysothamnus viscidiflorus	+++	+	+	++	++
Eriogonum microthecum	+			++	+
Leptodactylon pungens	++			+	+
Tetradymia canescens	+	+		+	
Grasses:					
Agropyron dasystachyum	+++	++	+		
Agropyron smithii	+	+			
Agropyron spicatum	++			+++	+++
Elymus cinereus	+		+++		
Elymus triticoides	++				
Oryzopsis hymenoides	+++	++	+	+	
Poa nevadensis	+			+	
Poa sandbergii	+			++	+
Sitanion hystrix	+++	++	+	+	+
Stipa comata	+++	+			
Forbs and Succulents					
Arabis spp.	++			+	+
Astragalus spp.	++			++	
Castelleja angustifolia	+			+	
Chaenactis douglasii	++				
Comandra umbellata	++	+			
Crepis acuminata	++			++	++
Erigeron pumilus	++			+	+
Lomatium triternatum	+				
Opuntia polyacantha	++	+			
Phlox hoodii	+++	+	+	++	+
Phlox longifolia	+			+	++
Sphaeralcea munroana	++				
Stanleya viridiflora	+				

ports a high diversity of forbs. Of the 389 species of plants identified on the INEL by Jeppson and Holte (1978), 71% were forbs. Some of the more common native forbs in the sagebrush steppe communities are shown in Table 1; most of these species are found in the other vegetation types as well. Because of its high forb diversity and protection from grazing, the INEL is an important reservoir of the genetic diversity of sagebrush steppe ecosystems.

The communities dominated by sagebrush present a continuously varying mosaic; the structure and composition of local stands is dependent upon local soils and topography, availability of propagules, disturbance history, herbivore impacts, etc. Long-term data from permanent plots at the INEL indicate that such factors coupled with year-to-year and long-term variation in precipitation preclude the convergence of different patches of vegetation on some stable species composition (Anderson and Inouye 1988). In other words, the concept of an equilibrium "potential" or "climax" community is probably inappropriate.

The vegetation of the area south of Highway 33 near Test Area North (TAN) is transitional between the characteristic sagebrush steppes of central portions of the INEL and the winterfat (*Ceratoides lanata*)/saltbush (*Atriplex* spp.) communities on ancient playas to the north. Here, Wyoming big sagebrush and winterfat are co-dominants, and horsebrush (*Tetradymia canescens*) and spiny hopsage (*Atriplex spinosa*) are common. Thickspiked wheatgrass, bottlebrush squirreltail, and Indian ricegrass are the most common understory species. Populations of western hedysarum (*Hedysarum boreale*), a forb having good potential for revegetation projects (see "Perennial Forbs" under "Characteristics of Recommended Species"), are found in this area.

Winterfat/Saltbush Communities

Communities dominated by winterfat, shadscale (*Atriplex confertifolia* and/or Nuttall saltbush (*Atriplex nuttallii*) are found on ancient playas west and north of TAN, on lacustrine deposits northeast of TAN, and on alluvial soils along Birch Creek and along the Big Lost River south of the Big Lost River Sinks. The soils of these communities are often moderately saline (Harniss and West 1973). These winterfat/saltbush communities are interspersed with sagebrush steppe, which develops on areas where more sand has been deposited. Some areas northeast of TAN along Highway 22 support nearly pure stands of winterfat. The most common grasses in these communities are bottlebrush squirreltail, Indian ricegrass, and thick-spiked wheatgrass (French and Mitchell 1983).

Great Basin Wildrye Communities

Communities dominated by Great Basin wildrye (*Elymus cinereus*) are found across the southern half of the INEL in scattered depressions between lava ridges and other areas where water from melting snow accumulates. These sites typically have deep soils that are relatively high in clay. Basin wildrye is a tall, robust grass that can use copious amounts of water during a growing season (Anderson et al. 1987). Thus, it has a competitive advantage on sites having deep soils that store large amounts of moisture. Great Basin wildrye communities may be comprised largely of the grass, or they may be co-dominated by basin or Wyoming big sagebrush or rubber rabbitbrush (*Chrysothamnus nauseosus*).

Threetip Sagebrush Communities

On the slopes of East Butte, Middle Butte, and Big Southern Butte, threetip sagebrush (*Artemisia tripartita*) replaces big sagebrush as the dominant shrub (Table 1).

Green rabbitbrush and shrubby buckwheat (*Eriogonum microthecum*) are common in these stands. Bluebunch wheatgrass is the most abundant species of grass; other common grasses include Sandberg's bluegrass (*Poa sandbergii*), and Nevada bluegrass (*Poa nevadensis*).

These communities often have a rich diversity of forbs.

Utah Juniper Communities

The foothills of the Lemhi Range west of Highway 22 and the high plateau south and east of Middle Butte and East Butte support stands of Utah juniper (*Juniperus osteosperma*). The understory of these communities is very similar in composition to the threetip sagebrush communities (Table 1). Big sagebrush, threetip sagebrush, green rabbitbrush, and shrubby buckwheat are common. Bluebunch wheatgrass is the dominant grass. Grasses and forbs may be quite abundant or rare, depending on the age and spacing of the juniper trees. Competition for soil moisture may eliminate most of the understory shrubs and herbs in dense, old-growth juniper stands.

Plant Cover

Absolute coverages of shrubs, grasses, and forbs have been measured at the INEL by numerous investigators. Shrub cover typically varies from 10% to 40%, grass cover from 1% to 10%, and forb cover from near zero to 10% (Floyd 1982, Marlette and Anderson 1986). In 1985, the average cover on 35 permanent plots representing vegetation of the central portion of the INEL was: shrubs, 18.6%; perennial grasses, 2.5%; perennial forbs, 1.2%; prickly pear cactus 0.7%, and annuals and biennials, 2.0%. Thus, total vascular plant cover was 25%, and the remainder of the area was bare ground, litter, rocks, etc. (Anderson and Inouye 1988). Local stands may differ markedly in structure (Anderson 1986), but communities typically are dominated by shrubs.

Cheatgrass Invasion

Cheatgrass (*Bromus tectorum*), an aggressive European annual, is locally abundant and is becoming more widely distributed on the INEL (Anderson and Inouye 1988). This is of concern because dense stands of cheatgrass have greatly increased fire frequency on sagebrush rangelands, virtually eliminating native perennial species from some areas. These conversions to communities dominated by annual plant species appear to be irreversible (Daubenmire 1970, Young and Evans 1973). The presence of cheatgrass has serious implications for restoration of burned areas and protection of native vegetation. More information can be found in the sections "Natural Disturbances," "Defining Objectives for Revegetation" and "Greenstripping."

Threatened or Endangered Species

So far as is known, no plant species classified as threatened or endangered by the U.S. Fish and Wildlife Service occurs at the INEL. However, Cholewa and Henderson (1984) identified nine species that are currently listed on the State Watch List. *Astragalus gilviflorus* and *Gilia polycladon* are classified as in danger of becoming extinct or extirpated from Idaho. *Astragalus kentrophyta* var. *jessiae*, *Camissonia pterosperma*, *Croyphantha missouriensis*, *Lesquerella kingii* var. *cobrensis*, and *Oxytheca dendroidea* are listed as "sensitive" because of small populations or localized distributions. *Astragalus ceramicus* var. *apus* and *Gymnosteris nudicaulis* are on the state monitor list (taxa that are uncommon or have a limited range, but

limited range, but have no identifiable threats at present). For information concerning the distribution of these taxa at the INEL, see Cholewa and Henderson (1984).

Wildlife Habitat

Mosaics of vegetation types, diversity of plant growth-forms, and variety in the numbers and kinds of plants all contribute to the maintenance of animal diversity (McArthur et al. 1978, Hingtgen and Clark 1984, Parmenter et al. 1985). Put simply, wildlife diversity is directly related to the structural diversity of plant communities (Dealy et al. 1981).

The INEL supports a diverse native fauna. Shrubs, particularly sagebrush, provide cover and food (especially in winter) for pronghorn, mule deer, sage grouse, jackrabbits, pygmy and cottontail rabbits and various small mammals. Some birds, such as the sage thrasher, sage sparrow, and Brewer's sparrow, are dependent upon shrubs for nesting habitat. Perennial grasses are important foods for both small and large mammals; forbs are often the preferred foods of pronghorn, deer, rabbits, and sage grouse during spring and summer. Parmenter et al. (1985), who studied reclamation of coal strip-mines in Wyoming, found that as shrub cover increased on revegetated areas so did the number of small mammals using the areas. Studies at the INEL have shown that not only does planting a single species like crested wheatgrass result in a monoculture of the grass or a biculture of crested wheatgrass and sagebrush for many years hence (Marlette and Anderson 1986), but it also reduces animal species diversity (Reynolds and Trost 1980).

PLANNING FOR RECLAMATION OF DISTURBED AREAS

Reclamation of disturbed lands often can be accomplished more effectively, efficiently, and economically if planning is initiated prior to the disturbance. Planning should include:

1. Consideration of the type and extent of disturbance.

Disturbances can be conveniently classified as natural or man- caused. In general, the more severe the disturbance, the more difficult it will be to rehabilitate the site. Careful planning can reduce both the areal extent and severity of disturbances. The types of disturbances and implications for planning are discussed in the next section, "Kinds of Disturbances."

2. Establishment of objectives for reclamation.

For most projects, planning to achieve three major goals must be integrated: preventing invasion of the site by weeds, stabilizing soil to control erosion, and establishing a self-perpetuating community of desirable plants that requires little or no maintenance. Planting to achieve the first and second goals without consideration of the third may make the third much more difficult to achieve. Guidelines for defining objectives are discussed in the section "Defining Objectives for Revegetation."

3. Collection of baseline data.

Knowledge of hydrology, soil characteristics and the composition of the pre-disturbance vegetation will facilitate reclamation planning. At the INEL, surface drainage patterns, infiltration and permeability characteristics of the soil, depth of the A

and B soil horizons, and depth to bedrock are important considerations. Soil scientists from the Soil Conservation Service (SCS) will make site visits and provide specific information on soil characteristics and their implications for reclamation. SCS personnel can also provide advice on seedbed preparation and planting. The address of the SCS office responsible for Butte County (which includes about 60% of the INEL) is: Arco Field Office, Soil Conservation Service, 125 Water Street, P.O. Box 819, Arco, ID 83213 (527-8557). All of INEL is under the jurisdiction of the SCS Pocatello Area Office, 850 E. Lander, Pocatello, ID 83201 (236-6843).

Baseline vegetation data should include a list of the vascular plant species present and information on their relative abundances (e.g. cover or frequency) as well as information about the structure of the vegetation (i.e., the arrangement of growth forms). If big sagebrush is present, identification of the subspecies (see Shumar et al. 1982, Shumar and Anderson 1986a, b) will provide an indication of soil depth and water availability.

4. Specification of species for planting and identification of sources of plant materials.

The science of restoring natural ecosystems in semiarid regions is in its infancy, and the choice of commercially-available plant materials, especially native shrubs and forbs, is severely limited. Therefore, consider the potential for collecting seeds or vegetative material from native species in the area to be used for seeding or producing transplants. The possibility of transplanting individuals from adjacent areas should also be considered. Characteristics and availability of plant materials and suggestions for using native plants from the vicinity are discussed in the section "Plant Materials for INEL Revegetation Projects."

Kinds of Disturbances

Natural Disturbances

1. Fire.

Wildfire is a natural component of the semiarid ecosystems at the INEL. In pre-settlement times, lightning strikes and aboriginal burning probably resulted in an average interval between recurring fires on a site of perhaps 50 to 100 years (Wright and Bailey 1982). Numerous fire scars, some probably dating to the last century are visible on aerial photos of the INEL. As a consequence of the long evolutionary history with fire, most native species are well adapted to cope with it. Historically, fires burned during the hot, dry months, late in the growing season, after most native grasses and forbs had completed their growth cycles and were dormant. Most of the perennial grasses and forbs, and some shrubs, will re-sprout following fire. Big sagebrush, the dominant shrub over much of the area, is killed by fire, but the production of large numbers of tiny seeds that are dispersed onto snow in winter adapts it well to recolonize areas.

Vegetation development following fire is largely dependent upon the composition of the vegetation prior to the fire (Bunting et al. 1987, Lyon and Stickney 1976). In sagebrush steppe having a good understory of perennial plants, the initial dominants following fire will typically be fast-growing perennial grasses and forbs that survive the fire and sprout following fall rains or in the spring. Some shrubs such as green rabbitbrush or horsebrush may also sprout and grow vigorously. In time, slower growing species or species such as sagebrush that must recolonize the area will become more

important. The time required for such species to reestablish depends largely on the distance from sources of propagules. Thus, large areas that have burned completely will be recolonized by non-sprouting species much more slowly than small areas or mosaics of burned and unburned land.

The timing and intensity of fire will also affect vegetation development. Some species are damaged more by fires early in the season, and others are more susceptible to late fires. Plant mortality will be higher with fires of high intensity. Nevertheless, areas where perennial grasses and forbs were common prior to the fire should recover nicely without intervention.

Dense, old-growth stands of sagebrush may have few perennial plants in the understory. Cheatgrass and other weedy annuals may be common, especially if some of the old sagebrush plants have died, reducing competition for water and nutrients. Fire through such a stand will likely result in a dense stand of annuals. Establishment of a dense stand of cheatgrass on such sites is of particular concern because areas supporting dense stands of cheatgrass are far more prone to fire than is the natural sagebrush steppe (Klemmedson and Smith 1964). Furthermore, there is ample evidence that cheatgrass does not relinquish a site to native species once it is established (Morrow and Stahlman 1984). The presence of extensive stands of cheatgrass would greatly increase the hazard of wildfire at the INEL. Therefore, rehabilitation following fire may be necessary in areas that do not have healthy populations of perennial species in the understory.

Land management agencies in western Idaho and other areas where extensive stands of cheatgrass occur have begun establishing firebreaks consisting of fire resistant plants to protect native sagebrush steppe. This technique, known as greenstripping, involves planting species such as crested wheatgrass, which tend to remain green late in the growing season, in strips 50 to 100 m (160 - 320 feet) in width. Greenstrips are established adjacent to roads or railways, around or interspersed in valuable shrublands (particularly around previously burned margins of high quality shrub habitat), or within large blocks of cheatgrass or other flash fuels in an attempt to reduce wildfire frequency and size. Research to identify more effective plant materials and to determine the efficacy and potential long-term effects of greenstripping is being conducted by the Bureau of Land Management and the Intermountain Research Station, USDA Forest Service. Further information may be obtained from the Idaho State Office, Bureau of Land Management. The section entitled "Characteristics of Recommended Species" includes further information concerning fire resistant characteristics of various species. For specific suggestions for greenstripping mixtures see the section "Greenstripping."

2. Wind Erosion.

Most INEL soils are of aeolian origin (McBride et al. 1978), thus wind has played a pivotal role in determining the present distribution and depth of soils. Linear sand dunes are common features on the northeastern quarter of the INEL, and "blowouts" as well as accumulations of sand in depressions or on the lee sides of outcrops are common elsewhere. Wind erosion may be severe on areas that have been recently burned, especially where shrubs dominated a prefire community having few perennial grasses in the understory. Soils often accumulate to depths of 20 - 30 cm (8 - 12 in) along the downwind edge of burned areas, contributing to the persistence of "fire scars" on the landscape

(J. Anderson and M. Shumar, personal observations; Morin- Jansen 1987).

3. Mammal burrows.

Badgers, pygmy and cottontail rabbits, and various small mammals create small areas of soil disturbance through their burrowing activities. Normally, such disturbances will not require reclamation, but they are of concern to the reclamation planner because the kinds of vegetation established may influence the kinds and numbers of burrowing mammals that will be present following reclamation. Studies at INEL have shown that small mammals may transport buried radionuclides to the surface (Arthur and Markham 1983) and their burrows may influence depths and rates of water infiltration following snowmelt or precipitation events (Laundré 1986).

Vegetation consisting of high species and structural diversity typically will support higher diversities and lower densities of small mammals than will vegetation dominated by one or a few species. Monocultures or plantings consisting of a single growth form (e.g., grasses) may encourage high densities of voles or ground squirrels (Groves and Keller 1983).

4. Ant colonies.

Harvester ants clear sizable areas around their mounds, as is quite obvious to anyone who has flown over the sagebrush steppe region. Sharp and Barr (1960) estimated that bare areas associated with ant mounds occupied from 3% to 7.5% of the area in salt sage communities in the Raft River Valley of southern Idaho. Sneva (1979) reported similar estimates for sagebrush grasslands of eastern Oregon. It is not uncommon for harvester ants to colonize reclaimed sites, but their impacts will usually be limited and not require further treatment. Studies are in progress at the INEL to determine the effects of ant colonies on water infiltration and the soil water balance (O. D. Markham, personal communication).

Human-caused Disturbances

Disturbances caused by human activities can be placed in two categories, those in which the soil profile remains intact and those in which the profile is severely disrupted or destroyed. (Human-caused fires are considered to be "natural" events; see #1 in previous section.) In general, the more severe the disturbance, the more difficult it will be to reclaim the site. Thus, minimizing the areal extent and severity of the disturbance will reduce costs and hasten reclamation efforts.

1. Soil profile intact.

In this category, the disturbance will likely result from compaction due to vehicles or heavy equipment, or from shallow blading. Depending on the length of time that the activities persist, and the timing of the activities (e.g. impacts may be minimal on frozen soils), many perennial plants and seeds in the soil may survive. Compaction impacts will generally be greatest in the late winter and spring when soils are wet. Therefore, avoiding disturbance activities during that time of year will reduce reclamation costs.

Minimizing the disturbance of the soil surface will reduce the opportunity for invasion of the site by undesirable weeds and minimize the costs and efforts required for reclamation. Take, for example, construction of a power line, fence, or temporary road that will only be used a short time. If possible, it would be better to drive over the existing vegetation than to blade a track. It doesn't take much traffic to kill brittle shrubs, but understory forbs and grasses may survive. Shrubs can be transplanted

onto the disturbed area to reduce visual impacts (see "Transplanting").

In cases where the compaction or blading has destroyed or removed the vegetation, it will probably be necessary to do some seedbed preparation prior to planting the area, particularly in heavy traffic areas that have been severely compacted (see "Seedbed Preparation").

2. Soil profile destroyed.

In general, the more severely the soil profile is disturbed, the more difficult and costly reclamation will be. When construction/development activities require excavation, the topsoil should be removed first and stockpiled so that it can be spread back on the site after excavations are backfilled. Minimizing the time that the topsoil remains in a stockpile will reduce mortality of soil microorganisms and facilitate the revegetation efforts. Stockpiled topsoil should not be allowed to become infested with weeds. Careful seedbed preparation normally will be required to insure plant establishment on severely disturbed sites (see "Seedbed Preparation").

Reclamation of disturbed sites should be undertaken as quickly as possible to preclude the establishment of populations of weedy species. Whenever possible, seeding or transplanting should be accomplished prior to the onset of the next growing season. Suggestions for seedbed preparation on sites where weed populations have become established are given in section "Seedbed Preparation."

Defining Objectives for Revegetation

In addition to consideration of the type and severity of disturbance, the specifics of a reclamation plan will depend upon the objectives of the effort. As a general guideline, INEL revegetation efforts should adhere to the requirements of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95- 87) which specifies that 1) disturbed areas must be returned to the approximate original contour, 2) a vegetative cover shall be established that is diverse, effective and permanent, equal to the cover that existed prior to the disturbance, and capable of stabilizing the soil surface from erosion, 3) disturbed areas shall be restored in a timely manner to conditions that are capable of supporting the uses supported prior to the disturbance, or higher or better uses (Tomlinson 1984). The land uses of particular relevance at INEL include the maintenance of wildlife habitat, native plant species diversity, and the overall ecological integrity of the National Environmental Research Park. To maintain native plant species diversity and the integrity of the gene pools of those species, we recommend using native species and local sources whenever possible.

Examples of specific objectives that might be appropriate for revegetation planning at the INEL are listed below. It is important to consider all of the objectives that are applicable to a particular project because meeting one objective in the most expedient manner may preclude or delay meeting others. Some of the implications and tradeoffs are discussed in the paragraphs that follow.

Potential objectives:

1. To stabilize the soil surface to prevent wind and/or water erosion.

2. To establish desirable perennial plants to discourage occupation of the site by populations of undesirable weeds.

3. To establish a stable, self-perpetuating community that will maintain itself without further cultural inputs.

4. To provide habitat for wildlife.

5. To provide an aesthetically-pleasing landscape that blends into the natural landscape of the area.

6. To preclude water received as precipitation from reaching buried wastes.

7. To establish fire-breaks by planting fire-resistant species.

Both wind and water erosion can be controlled effectively by establishing a cover of rhizomatous or tussock-forming perennial grasses. Reclamation planners often assume that pure stands of such grasses will eventually revert to diverse communities of native species through natural succession. Research has shown, however, that pure stands of species such as crested wheatgrass are very stable, inhibit establishment of other species, and may preclude the development of diverse natural communities (Anderson and Marlette 1986, Marlette and Anderson 1986). Crested wheatgrass often is included along with native species in reclamation plantings to insure establishment of plant cover and provide forage. However, because of its prolific seed production and competitive superiority, crested wheatgrass likely will become the dominant species on sites to which it is well adapted, regardless of its proportion in the original seed mixture (Schuman et al. 1982). *Therefore, if the objectives include restoring a diverse community of native species, the species chosen for planting should include only native species.*

There are situations where it may be desirable to establish pure stands of perennial grasses that will remain stable and resist invasion by native species. One case is along highways and other improved roads at the INEL. Many of the roadways are flanked by stands of crested wheatgrass. Such stands provide a barrier of moderately fire-resistant vegetation (see "Greenstripping"), and they resist invasion of the area by weeds as well as native species that may be much more flammable. Crested wheatgrass is tolerant of mowing, especially after seeds have matured. Therefore, roadsides can be mowed late in the season to further reduce fire hazard. Unfortunately, INEL maintenance personnel have not recognized these values. The sides of highways routinely are bladed or treated with chemicals to remove vegetation. This disturbs the soil and encourages establishment of flammable weeds, which necessitates, in turn, repeated blading or spraying. Maintenance of good stands of perennial wheatgrasses would reduce costs, improve aesthetics, reduce the need for spraying for noxious weeds, and provide reasonable fire protection. Specific suggestions for roadside seedings are given in the section "Waste Management Sites and Roadsides."

In semiarid regions, it is possible to preclude moisture from reaching interred wastes by providing a cap of soil sufficient to store that portion of the annual precipitation that falls outside the growing season and a cover of vegetation that will use all of the available moisture during each growing season, thereby renewing the storage capacity of the soil. Our studies at the INEL have shown that a cap 1.4 m (4.6 ft) in depth would be adequate to store all of the precipitation received between October 1 and May 31, provided that the soil was dried to the lower limit of plant extraction during the previous growing season (Anderson et al. 1987). Any of a number of perennial species could be established to use the stored moisture on such sites (ibid.), but crested wheatgrass has several advantages. It can be established quickly from seed or by transplanting (Shumar and Anderson 1987). It is very competitive for soil moisture and capable of drying soils to

depths of over 2 m (Anderson et al. 1987). Growth rates and evapotranspiration are high, and stands of crested wheatgrass are capable of using all of the water that would be expected to fall in the wettest of years (J. Anderson, unpublished data). Crested wheatgrass tolerates repeated mowing, but if the objective is to maximize evapotranspiration, the stand should not be mowed until the plants "cure" late in the season.

Natural communities at the INEL are assemblages of shrubs, perennial grasses, and forbs. Therefore, when the objectives include restoration of wildlife habitat and development of naturally- appearing communities, care should be taken to insure that representatives of all three growth forms are established. A community consisting of shrubs, grasses, and forbs will provide a diverse habitat for many species of wildlife.

PLANT MATERIALS FOR INEL REVEGETATION PROJECTS

Once the objectives for the revegetation project have been established, species that will meet those objectives must be selected. The success of a revegetation project is dependent upon selecting species that are adapted to the soils and climate of the area. Adapted species are those that grow well, complete their life cycles, reproduce, and maintain viable populations over long periods on the site. This definition includes both native and introduced species.

Populations of the native species of an area are obviously well adapted; thus, local patches of undisturbed vegetation can serve as a guide for species selection. There can be, however, tremendous genetic variability among populations within a species. This is especially true of species that have wide geographic distributions, which includes most of the dominant or common species at the INEL. Such species typically consist of many local populations, or "ecotypes," that are genetically adapted to the local environment. Thus, propagules from New Mexico or Utah, or even western Idaho, may not be adapted to the upper Snake River Plain, despite the fact that the same species grows in both areas. Sources of plant materials should be sought such that the difference between the genetics of the plants used for revegetation and that of surrounding natural populations of the same species is minimized. The best sources, therefore, may be seeds or transplant stock from the surrounding native areas (see "Wildings").

Seeds for a variety of grasses, some forbs, and a few shrubs are available commercially (see "Sources of Plant Materials"). Usually, these are varieties that have been developed and "released" to commercial growers by Soil Conservation Service (SCS) Plant Materials Centers or the Shrub Sciences Laboratory (USDA Forest Service) in Provo, Utah. Certification programs are designed to maintain the genetic integrity of released varieties. These varieties typically have been selected for good performance on a variety of sites and are, therefore, broadly adapted. By convention, the names of released varieties are enclosed in single quotation marks (e.g. 'Sodar' streambank wheatgrass).

The INEL Experimental Garden

In the fall of 1983, a garden was established at the INEL Experimental Field Station for the purpose of evaluating establishment

and persistence of commercially-available seeds and nursery stock. Also planted were seeds collected from native populations at the INEL and seeds from accessions that were being evaluated for potential release by the SCS Plant Materials Center at Aberdeen, Idaho. Seeds for many of the test species were provided by the Aberdeen center.

The garden was established on a site that previously had been cultivated and planted to crested wheatgrass. The site was disked and "rototilled" in the fall of 1982 and then "rototilled" again after the 1983 growing season to control weeds and crested wheatgrass plants that had sprouted. Seeds of 30 species, 15 grasses, 8 forbs and 7 shrubs, were planted in November, 1983, or April, 1984. Seeds of each test species were drilled into a 10-m (32.8-ft) long row using a hand seeder (See "Drill Seeding by Hand or With Tractor-mounted Planters"). Rows of test species were separated by two "guard rows" of 'Sodar' streambank wheatgrass (*Agropyron dasystachyum*). Rows were 0.6 m (2 ft) apart. The garden has not been irrigated or fertilized; however, it has received periodic weeding between the rows.

Container-grown individuals of four species of shrubs were obtained from Native Plants, Salt Lake City, Utah, and transplanted into the garden in May of 1984. Included were 24 fringed sagebrush (*Artemisia frigida*), 24 rubber rabbitbrush (*Chrysothamnus nauseosus*), 33 four-wing saltbush (*Atriplex canescens*) and 27 shadscale (*Atriplex confertifolia*) plants. The plants were irrigated on the day they were transplanted, but received no further supplemental water. The area around the shrubs was weeded periodically.

Performance of the seeded species was evaluated by measuring the portion of the 10-m row that was occupied by the test species in July of 1984 and 1986. These results, our subjective ranking of how well various species performed in the garden (and other INEL revegetation projects if applicable), and characteristics of the species planted in the garden are summarized in Table 2. Additional information about the species that are recommended for revegetation projects at the INEL is found in the next section.

Characteristics of Recommended Species

Perennial Grasses

1. Crested Wheatgrasses. -- The crested wheatgrasses (*Agropyron desertorum*, *A. cristatum*, and *A. sibiricum*) are long-lived perennial bunchgrasses native to the steppes of Asia. They are well adapted to semiarid regions and tolerant of grazing, so they are commonly used in reclaiming disturbed sites and rehabilitating overgrazed rangelands in western North America (Rogler and Lorenz 1983, Young and Evans 1986). The crested wheatgrasses are vigorous competitors (Eissenstat and Caldwell 1988) and prolific seed producers (e.g., Marlette and Anderson 1986). In their native habitats, they are known for their ability to establish on disturbed sites and persist in virtual monocultures (Looman and Heinrichs 1973). Many areas that have been seeded to crested wheatgrasses are virtual monocultures; such stands are exceptionally stable and resist invasion by native species for at least 30 - 50 years (Hull and Klomp 1966, Looman and Heinrichs 1973). Stands of crested wheatgrass at the INEL also are very stable (Anderson and Marlette 1986, Marlette and Anderson 1986). When sown in mixtures with native species, crested wheatgrass frequently becomes the dominant species (Heinrichs and Bolton 1950, Schuman et al. 1982); there-

Table 2. Characteristics of selected species that have been evaluated at the INEL experimental garden or in other INEL revegetation projects. Cover refers to the percentage of a 10 m (33 ft) row covered by a species in the year indicated. Grasses and forbs were planted in the fall of 1983. Performance was rated from poor to excellent based on growth and survival in the INEL experimental garden and other projects. For additional information on these species, see "Characteristics of Recommended Species." Additional information on planting can be found in the section "Revegetation Techniques." For recommended seeding mixtures, rates, and planting methods see "Recommended Seeding/Planting Mixtures".

	Origin	Cover Year 1	Cover Year 2	Performance	Uses*
Grasses:					
'Whitmar' bluebunch wheatgrass (*Agropyron spicatum*)	Native	56	70	Good	1
P-739 bluebunch wheatgrass (*Agropyron spicatum*)	Native	71	73	Excellent	1
'Rosana' western wheatgrass (*Agropyron smithii*)	Native			Good	1
'Secar' Snake River wheatgrass (*Agropyron dasystachym*)	Native	48	61	Good	1
'Critana' thick-spiked wheatgrass (*Agropyron dasystachyum*)	Native	75	89	Excellent	1
'Sodar' streambank wheatgrass (*Agropyron dasystachyum*)	Native			Excellent	2,3,4
'Ephraim' crested wheatgrass (*Agropyron desertorum*)	Exotic	83	90	Excellent	2,3,4
'Nordan' crested wheatgrass (*Agropyron desertorum*)	Exotic			Excellent	2,3,4
P-27 Siberian wheatgrass (*Agropyron sibiricum*)	Exotic	77	81	Excellent	2,3,4
'Ruff' crested wheatgrass (*Agropyron cristatum*)	Exotic	76	85	Excellent	2,3,4
'Magnar' Great Basin wildrye (*Elymus cinereus*)	Native	33	53	Good	1,4
Bozoisky' Russian wildrye (*Elymus junceus*)	Exotic	74	81	Excellent	(1),4
'Nezpar' Indian ricegrass (*Oryzopsis hymenoides*)	Native	3	0	Poor	1
Paiute' orchard grass (*Dactylis glomerata*)	Exotic	82	52	Excellent	(1),4
'Canbar' canby bluegrass (*Poa scabrella*)	Native	9	0	Poor	NR

(Table 2, cont.)

	Origin	Cover Year 1	Cover Year 2	Performance	Uses
'Covar' sheep fescue (*Festuca ovina*)	Native	15	49	Fair	NR
'Joseph' Idaho fescue (*Festuca idahoensis*)	Native	17	21	Fair	NR
Perennial forbs:					
'Appar' Lewis flax (*Linum perenne*)	Native	86	92	Excellent	1,4
'Bandera' Rocky Mtn. Penstemon (*Penstemon strictus*)	Native	64	64	Excellent	1
T-3885 Palmer penstemon (*Penstemon palmeri*)	Native	4	5	Poor	NR
'Delar' small burnet (*Sanguisorba minor*)	Exotic	50	45	Good	(1),4
Western hedysarum (*Hedysarum boreale*)	Native	40	40	Good	1
'Lutana' cicer milk-vetch (*Astragalus cicer*)	Exotic	63	70	Excellent	(1),4
Shrubs:					
Wyoming big sagebrush (*Artemisia tridentata*)	Native			Excellent	1
Fringed sagebrush (*Artemisia frigida*)	Native			Excellent	1
Green rabbitbrush (*Chrysothamnus viscidiflorus*)	Native			Excellent	1
Gray rabbitbrush (*Chrysothamnus nauseosus*)	Native			Excellent	1
Winterfat (*Ceratoides lanata*)	Native			Excellent	1
Prostrate kochia (*Kochia prostrata*)	Exotic			Unknown	NR

*Recommended uses are coded as follows: 1 = restoration of natural communities, 2 = waste management areas, 3 = roadsides, 4 = greenstripping, (1) = non-native species that might be used for restoration of natural communities. NR = not recommended. See text for further details.

fore, seeding crested wheatgrass in a mixture with native species is not recommended if the goal is to restore a natural, diverse community.

Most of the crested wheatgrass that has been planted at the INEL is probably standard or 'Nordan' (*A. desertorum*). It is likely that 'Fairway' crested wheatgrass (*A. cristatum*) has also been used. As indicated above, these varieties are well adapted to the area and were, therefore, not included in the experimental garden. Other varieties included in the garden are discussed in the following paragraphs; performance of all three was rated excellent (Table 2).

'P-27' Siberian wheatgrass (*A. sibiricum*) is very drought tolerant. It is shorter in stature and less productive than 'Nordan' or 'Fairway'. Its fine leaves and stems make it more nutritious and palatable than other crested wheatgrasses. Because it tends to stay green 1 - 2 weeks longer than other crested wheatgrasses (Gebhardt et al. 1987), it is often recommended for greenstripping mixtures (see "Greenstripping").

'Ephraim' crested wheatgrass is a rhizomatous variety of *Agropyron cristatum*. It was released to commercial growers in 1982 (Stevens and Monsen 1985). Individuals of this variety are shorter than those of other crested wheatgrasses. Because it is rhizomatous, it is especially well suited for stabilization of disturbed sites. Under irrigation, it will develop rhizomes in one year, but rhizome development is slower under natural precipitation (ibid.), and rhizomes may not develop when it is grown at the lower end of its precipitation range (N. Shaw, personal communication). It does best in areas receiving between 250 and 350 mm (10 to 14 in) of precipitation (ibid.), which is somewhat higher than the mean at INEL.

'Ruff' crested wheatgrass is a dwarf form of (*A. cristatum*) that closely resembles 'Fairway'. It has a spreading, broad-bunch growth habit and short, leafy culms; it has been recommended for areas such as roadsides and parks in drier semiarid regions (Asay 1983). Sours (1983) noted that its use for rangeland seedings has been minimal and most of the seed- producing stands have been plowed; therefore, seeds for this variety may not be readily available.

2. Bluebunch Wheatgrass. -- Bluebunch wheatgrass (*Agropyron spicatum*), a long-lived perennial, has long been recognized as one of the most valuable native grasses in the Intermountain West and Pacific Northwest. Because of its excellent forage quality, it often is preferentially grazed; thus, many populations have been severely depleted by overgrazing. It is uncommon at the lowest elevations on the central portion of the INEL, but is a dominant grass at slightly higher elevations on the east, south, and west sides of the site. Two varieties, 'Whitmar' and 'P739' were seeded into the experimental garden (Table 2). 'Whitmar' is available commercially; it became established more slowly than the crested wheatgrasses, but its population increased markedly between 1984 and 1986. Establishment of 'P739' was comparable to that of the crested wheatgrasses. Plans call for this variety to be released by the Aberdeen Plant Materials Center as 'Goldar' in 1989, thus commercial seed may be available in the near future. These varieties are recommended when the objective is to establish native species. Our results suggest that 'P739' ('Goldar') would be the best choice.

3. Thick-spiked and Streambank Wheatgrasses. -- Thick-spiked and streambank wheatgrasses (*Agropyron dasystachyum*) are native rhizomatous perennials. Thick-spiked wheatgrass is abundant over much of the central portion

of the INEL; it is often the dominant grass present. The released variety 'Critana' established as well as the crested wheatgrasses in the INEL garden (Table 2). 'Secar' established more slowly, but its cover increased between 1984 and 1986 (Table 2). Asay (1983) noted that 'Secar' was quite drought tolerant. 'Sodar' was not included as a test species in the garden, but was planted in the "guard rows" between the other species. Establishment of this species was excellent and it grew vigorously. This species was also seeded on simulated waste burial trenches where it produced vigorous stands; information concerning its rooting depths and water use characteristics can be found in Anderson et al. (1987). 'Sodar' stays green later in the season than do the crested wheatgrasses, and it is not very palatable to either livestock or wildlife. For these reasons, it is the main species used by the Idaho Transportation Department for roadside plantings in southern Idaho (Gebhardt et al. 1987). It provides a fire- resistant vegetation that does not attract wildlife. Seeds for 'Critana', 'Secar', and 'Sodar' are available commercially.

4. Western Wheatgrass. -- Western wheatgrass (*Agropyron smithii*) is a native rhizomatous grass. Though not common at the INEL, scattered stands are present. This species stabilizes soils and is a palatable forage. Western wheatgrass was not included in the experimental garden, but we did plant the commercial variety 'Rosana' in test plots on a decontamination- decommission site where it established well. The variety 'Arriba' is more drought tolerant and may be a better choice for INEL projects.

5. Great Basin Wildrye. -- Great Basin or giant wildrye (*Elymus cinereus*) is a large, robust perennial bunchgrass that is found throughout the Intermountain West on deep soils and disturbed sites. Great Basin wildrye is easily damaged by spring grazing (Perry and Chapman 1975), and only remnants of the vast stands that once occurred in the Great Basin remain (Sours 1983, Lesperance et al. 1978). However, it provides good winter forage and cover. At the INEL, it frequently occurs in relatively pure stands in depressions or low-lying areas where deep soil accumulates. Individuals are long-lived and large, reaching 2 m (6.6 ft) in height. On deep soils, stands are very productive and have high seasonal water use. In experiments at INEL, stands of this species have used a quantity of water equal to 2.4 times the average annual precipitation (Anderson et al. 1987). Establishment in the INEL garden was somewhat slower than that of the wheatgrasses (Table 2), but once established it persisted and the population increased in size. Because of its stature, it is aesthetically pleasing and adds height diversity to the community. It is a good choice for alkaline or saline areas. Commercial seeds for the variety 'Magnar' are available; planting of this variety should be restricted to low- lying sites having deep soils. Seeds from local sources could be collected. Individuals can also be transplanted as wildings (Shumar and Anderson 1987; see "Wildings").

6. Orchard Grass. -- Orchard grass (*Dactylis glomerata*) is a Eurasian grass that has been introduced to much of North America for hay and pasture. It is a very palatable forage species. The released variety 'Paiute' was selected for drought tolerance. Although usually recommended for sites receiving at least 300 mm (12 in) of precipitation, it established very well in the INEL garden (Table 2). Its cover decreased between 1984 and 1986 as a result of heavy rodent herbivory. It could be included in seed mixes with native species to provide additional forage for wildlife. Also, it tends to remain green late in the season and thus may be a desirable component of fire- resis-

tant vegetation (see "Greenstripping"). However, it probably will attract small mammals and should be not be planted where that would be undesirable (e.g. waste burial sites).

7. Russian Wildrye. -- Russian wildrye (*Elymus junceus*) is an introduced perennial bunchgrass. Once established, it produces abundant early-season forage, is drought and cold tolerant, and has excellent forage quality (Asay 1983). It will remain green and grow during the summer if moisture is available, and it retains its nutrient value better than many other grasses in late summer and fall (ibid.). Russian wildrye often has poor seedling vigor and establishes slowly (N. Shaw, personal communication), but establishment of the variety 'Bozoisky' was excellent in the INEL garden. This species could be included in seed mixes with native species to provide forage for wildlife, and it too may have potential as a component of greenstripping mixtures (see "Greenstripping"). The variety 'Bozoisky select' is now available.

8. Indian Ricegrass. -- Indian ricegrass (*Oryzopsis hymenoides*) is one of the most common native bunchgrasses at the INEL. A palatable species, it is an important component of the diets of large herbivores, small mammals, birds, and ants. It produces large, nutritious seeds, which are favored foods of heteromyid rodents, birds, and seed-eating ants. It is also a very attractive grass and is recommended for seeding where the objective is to restore natural habitats. Unfortunately, most Indian ricegrass seed is difficult to germinate and establishment is often poor. The recently released variety 'Nezpar' has good germination, but it did not establish well in test seedings at the INEL (Table 1). The SCS recommends that 'Nezpar' be used only on sites having sandy loam soils (J. Gibbs, personal communication). For other sites, we recommend using seed collected locally. There are some extensive stands of Indian ricegrass on the northeastern side of the INEL from which it should be possible to collect seed in most years.

Perennial Forbs

1. Lewis Flax. -- Lewis or wild blue flax (*Linum perenne*) is a native species found throughout much of western North America. Lewis flax is colorful, aesthetically attractive, and very palatable; it produces vigorous seedlings that compete well with grasses, shrubs, or other forbs when seeded in mixtures (Shaw and Monsen 1983). Wildings, bare-root stock, or container-grown seedlings can be readily transplanted (see "Transplanting"). The commercial variety 'Appar' has been used widely for roadside plantings and habitat restoration in semi-arid regions of the Intermountain West. It established exceptionally well, grew vigorously, and produced abundant flowers in the INEL garden (Table 1). This species is highly recommended where the objective is to restore a diverse community of native species.

2. Penstemon. -- There are numerous native penstemons in the Intermountain West. Five native species have been collected at the INEL. Several varieties have been developed and released by SCS Plant Materials Centers, the Forest Services' Intermountain Station, and the Utah Division of Wildlife Resources. Two of these were included in the experimental garden. 'Bandera' Rocky Mountain penstemon (*Penstemon strictus*) established and grew very well (Table 2). Establishment of Palmer penstemon (*P. palmeri* was only fair (Table 2), but because of the paucity of native forbs for which commercial seeds are available, we have included it as a recommended species. 'Cedar' Palmer penstemon has recently been released

(Stevens and Monsen 1988a). It is a large, showy variety that produces succulent foliage for wildlife. It establishes best on areas receiving from 250 to 400 mm (10 to 16 in) of precipitation (which may be the reason for limited establishment in the INEL garden), but once established will persist on sites receiving as little as 200 mm (8 in) of moisture (Stevens and Monsen 1988a). Thus, once established it should persist well at the INEL. Because of its abundant flowers and persistent foliage, it is also useful for landscape plantings.

3. Small Burnet. -- Small burnet (*Sanguisorba minor*) is an exotic forb from Europe that is being used increasingly in reclamation plantings in the western United States because of its value to wildlife. Small burnet remains green all year and is very palatable. Good establishment was observed in the INEL garden (Table 2), and it has persisted despite considerable herbivore pressure. Because it is evergreen, it has potential for use in greenstripping mixtures (Gebhardt et al. 1987). It is also very attractive and can be used for landscape plantings.

4. Western Hedysarum. -- Sweetvetch or northern hedysarum (*Hedysarum boreale*), a native legume, is quite common on northern portions of the INEL. Establishment in the INEL garden from seed collected south of TAN was good (Table 2), indicating that this species has excellent potential for reclamation projects. This species also can be propagated vegetatively (Rumbaugh 1983), so it should be possible to transplant wildings (see "Wildings") from natural populations to reclamation sites. Testing of numerous accessions (including one from the INEL) by the Intermountain Station, Forest Service, is underway (S. Monsen, personal communication), so it is likely that a released variety will become available within a few years.

Shrubs

1. Sagebrush. -- The most abundant shrubs at the INEL are sagebrushes. Several species occur, but by far the most common is big sagebrush *Artemisia tridentata*. Two subspecies of big sagebrush are found; the most common is Wyoming big sage (Shumar and Anderson 1986a). Wyoming sagebrush is smaller in stature (typically < 1 m tall) and more drought tolerant than basin big sagebrush. Basin big sagebrush usually is found on deeper soils, often where sand has accumulated on the surface (Shumar and Anderson 1986a). Basin big sagebrush is common on eastern portions of the INEL, and near the Big Lost River it often is found in old stream channels, whereas Wyoming big sagebrush occurs on adjacent uplands.

Many species of wildlife at the INEL are dependent upon sagebrush for food and cover. Pronghorn and sage grouse depend on sagebrush for food in winter, songbirds such as the sage thrasher, sage sparrow, and Brewer's sparrow, require sagebrush for nesting habitat, and sagebrush provides cover and food for jackrabbits, pygmy rabbits and various smaller mammals.

We did not include sagebrush in the experimental garden because commercial varieties were not available. However, this is one of only a few shrubs that can be seeded directly with grasses, and stands often develop quickly (S. Monsen, personal communication). If sagebrush seed is used, it should be collected from the site or from stands of the desired subspecies from nearby locations. Commercial collectors can be contracted to collect seeds from local sources (see "Sources of Plant Materials"). Sagebrush flowers in late summer-early fall, and seeds ripen in late fall or early winter. The seeds are short-lived and should be planted in the winter or spring following maturity. Sagebrush seeds are

tiny and are difficult to plant using conventional drills because the seeds are easily buried too deep. However, they can be seeded with a cultipacker or broadcast (see "Seeding"). Good establishment requires a firm seedbed.

We have had excellent success transplanting small sagebrush plants from natural stands to reclamation or experimental plots (Shumar and Anderson 1987). We recommend transplanting such wildings to establish sagebrush plants at low densities on reclamation sites. These plants then will serve as centers of dispersal from which the population may spread. Because it is neither necessary nor desirable to establish sagebrush at high densities, transplanting individuals from adjacent natural stands is both feasible and economical (see "Wildings").

2. Fringed Sagebrush. -- Fringed sagebrush or fringed sagewort (*Artemisia frigida*) is a native suffrutescent shrub. It is found from the Great Plains to British Columbia, Alaska, and Siberia. It often is found on coarse, shallow soils and cold sites. It is moderately palatable and provides excellent browse for wildlife, especially in late fall and winter. Its distribution in Idaho is limited, and it is not common at the INEL. However, container-grown plants transplanted to the INEL garden grew very well and produced an abundance of seed, suggesting good potential for use in reclamation projects in the area. All 24 plants placed in the INEL garden survived and grew vigorously.

3. Rabbitbrush. -- Two species of rabbitbrush are common at the INEL. The most abundant is green rabbitbrush (*Chrysothamnus viscidiflorus*). Although not very palatable, this species provides a late-season source of nectar and it is an important winter food for jack rabbits. Green rabbitbrush often sprouts following fire and also spreads readily from natural seeds. Like big sagebrush, it establishes well from direct seeding. Seed should be collected from local sources. It also can be readily transplanted (Shumar and Anderson 1987), so an alternative strategy for reclamation projects is to move small individuals from adjacent areas onto the site to establish centers of dispersal (see "Wildings").

Gray rabbitbrush (*Chrysothamnus nauseosus*) is more palatable and can be an important browse species for wildlife. Considerable research is underway to identify and release widely-adapted varieties of this species, and container stock of accessions adapted to the INEL may become available.

4. Winterfat. -- Winterfat (*Ceratoides lanata*) is a nutritious, palatable, drought-tolerant suffrutescent shrub that is an important constituent of many communities at the INEL. Some nearly monotypic stands of winterfat occur on the northern side of the INEL. Commercial seed is available, but care should be taken to insure that the seed is from a local source. In 1982, we broadcast seeds of winterfat as part of an experimental seeding on a demonstration reclamation plot (see "What to Expect -- Evaluation of Success"). Establishment of winterfat plants on that plot was quite good.

Recently, a strain of winterfat known as 'Hatch' was released by the Utah Division of Wildlife Resources and others (Stevens and Monsen 1988b). This accession was collected in south-central Utah and is best adapted to upland sites having higher precipitation than the INEL. Therefore, 'Hatch' is not recommended for INEL reclamation projects.

5. Prostrate Kochia. Prostrate kochia (*Kochia prostrata*), also know as forage kochia or summer cypress, is an exotic shrub that was introduced from the semi-arid regions of southern Eurasia, where it is often associated with crested wheatgrass (Stevens et al. 1985). It is a long-lived, low-

growing, palatable species that is receiving increased consideration for use in reclamation plantings. Because it tends to remain green, there is also interest in its potential in fire-resistant greenstrips (Gebhardt et al. 1987). There is concern, however, that it may become a weedy pest because it can spread aggressively from seed (Keller and Bleak 1974). Until more information is available on its establishment and spread on Wyoming sagebrush sites, we recommend that it not be planted at the INEL.

Additional information on many of the species described herein as well as a number of other grasses, forbs and shrubs can be found in Section 3 of the reference by Monsen and Shaw (1983).

—Sources of Plant Materials

A few local suppliers of plant materials for INEL revegetation projects are listed below. Numerous additional sources exist; current listings of suppliers and information regarding release and availability of new varieties can be obtained from the SCS Plant Materials Center, Box AA, Aberdeen, Idaho 83210. Names and addresses of commercial seed collectors can be obtained from the Aberdeen Plant Materials Center or from the Shrub Sciences Laboratory, USDA Forest Service, 735 North 500 East, Provo, Utah.

The Idaho Grimm Growers Warehouse Corp.
P.O. Box 276
Blackfoot, ID 83221
Phone: (208) 785-0830
Plant Materials: grass, forb, and shrub seeds; native and exotic species

Maple Leaf Industries, Inc.
480 South 50 East
Ephraim, UT 84627
Phone: (801) 283-4701
Plant Materials: grass, forb, and shrub seeds; native and exotic species

Granite Seed Company
1697 West 2100 North
Lehi, UT 84043
Phone: (801) 768-4422
Plant Materials: grass, forb, and shrub seeds; native and exotic species; native seed collecting and cleaning

Porter-Walton Wholesale Nursery
262 West 400 South
Centerville, UT 84014
Phone: (800) 533-8498
Plant Materials: container-grown and bare root stock, shrubs and forbs

REVEGETATION TECHNIQUES

Seeding

Seedbed Preparation

Prior to planting, adequate site preparation is essential to provide a suitable environment for seed germination and seedling establishment. An ideal seedbed would be firm below the seeding depth, but well pulverized and loose on top to enhance moisture infiltration and provide good seed-to-soil contact (USDA Forest Service 1979, Vallentine 1971). It would be free from clods and would contain mulch on the surface to retard evaporation. It would be free of seeds of potential competitors as well as competition from resident plants. Such conditions often are difficult to achieve on arid rangeland sites, but the extent to which they are achieved may well determine the success of the seeding effort. The farmers'

adage "have a good firm seedbed" applies to reclamation projects as well (Young and Evans 1987).

The amount of seedbed preparation required depends on the severity of the disturbance, the condition of the site, and the objectives of the revegetation plan (see "Planning for Reclamation of Disturbed Areas"). Where disturbance has been light and/or it is desirable to preserve native species that are growing on the site, tillage should be avoided or minimized. In such cases, it may be possible to drill or broadcast seed without any seedbed preparation. Small areas of severe disturbance within a larger area that has been subject to only light disturbance can be seeded by hand (see "Drill Seeding By Hand or With Tractor-mounted Planters") rather than increasing the level of disturbance and destroying residual populations of desirable species. Transplanting wildings or nursery-grown plants should also be considered (see "Transplanting).

On sites where soils have been compacted by vehicular traffic or construction activities, where fill soils have been emplaced and packed, where native vegetation has been destroyed, or where populations of undesirable species have become established, more extensive tillage is required. Tillage may be conveniently divided into primary and secondary operations (USDA Forest Service 1979). Primary tillage refers to relatively deep operations such as ripping, plowing, chisel plowing, or disking with offset disks or disk plows. Primary tillage usually leaves a rough surface, and additional tillage may be required to achieve the desired seedbed characteristics, especially if the seed is to be drilled.

Offset disks, or the heavier offset disk plows, are designed to turn the surface materials under. This will bury viable seeds in the upper few centimeters of the soil and should provide a relatively weed free seedbed, provided that secondary tillage doesn't bring seeds back to the surface. Offset disks, disc plows, and chisel plows are used routinely by farmers of southeastern Idaho, so it should be possible to find local contractors for this kind of work.

Secondary tillage works the soil to a shallow depth, breaking clods, smoothing the surface, and compacting the seed bed. Secondary tillage may be all that is needed on sites that have not been severely compacted and are relatively free of weeds. Implements used include disk harrows, roller harrow-packers (cultipackers), and tooth-type harrows (USDA Forest Service 1979). Tooth-type harrows may be most effective if the surface left by primary tillage is very rough with large clods. Cultipackers do a good job of pulverizing and firming the soil and provide an excellent seedbed for drilling.

Rotary tillers can also be used for secondary tillage, but they may bring weeds seeds buried by the primary tilling operation back to the surface. Rotary tillers can be used to reduced competition from annuals such as cheatgrass by tilling in the spring after most seeds have germinated. However, this kind of tilling in the fall or early spring may increase the density of weeds (Gebhardt et al. 1987). Fall and spring tilling can be helpful in controlling weed populations. Rotary tillers are restricted to sites that are relatively free of rocks. They do an excellent job of pulverizing the soil, but the soil must be packed with a cultipacker or similar roller packer prior to drilling. Alternatively, seed could be broadcast onto the tilled site and then covered with a cultipacker. Rotary tillers are used extensively by potato farmers in southeastern Idaho.

A typical tillage scenario for a site at the INEL where the soil has been severely disturbed and compacted would include 1)

primary tillage with an offset disk to loosen the top 20 cm and bury seeds that are near the soil surface and 2) secondary tillage with a cultipacker to prepare the site for drilling. More intensive site preparation, including successive tillings or mechanical scalping, may be necessary on small areas where populations of weeds have become established.

Seeding With a Cultipacker

Cultipackers equipped with seed boxes are highly recommended for seeding at sites where secondary tillage is planned (see "Seedbed Preparation"). Cultipackers can be equipped with several seed boxes that allow seeding different species in individual strips. The seedboxes are mounted between two cultipackers. The front cultipacker smooths and packs the seedbed while creating small furrows. The seed is broadcast onto the ground from the seedboxes. The second cultipacker, which is offset, fills in the original furrows and creates new ones. This results in seeds being covered to various depths, so some of the seeds will be planted near their optimum depth for germination and establishment. Because the resulting vegetation doesn't grow in rows, it is more natural in appearance.

Cultipackers equipped with seed boxes are manufactured by Brillion Iron Works, 200 Park Ave., Brillion, Wisconsin 54110. Some commercial operators that do custom planting in the region may have cultipackers equipped with seed boxes; names and addresses of such contractors can be obtained by asking the State Office of the Bureau of Land Management for a recent list of revegetation project bidders.

Drill Seeding

A drill is an implement that accurately meters seeds, places them into a furrow, and covers them with soil. Numerous kinds of drills have been developed; their uses in reclamation work are described by USDA Forest Service (1979) and Young and Evans (1987). We need only be concerned with two of these, the conventional grain drill and the rangeland drill.

Most grain drills are equipped with double-disk furrow openers and press wheels to insure precise placement and firm coverage of the seeds. This type of drill is preferred, especially for seeding grasses, on sites that are relatively free of rocks and other obstacles and have a good seedbed. But, their use is restricted to arable sites.

The rangeland drill was developed in the 1950's for use on rough terrain (Young and Evans 1987). It is a ruggedly-constructed implement having independently-suspended furrow openers and large wheels for negotiating obstacles. Rangeland drills can be used with little or no seedbed preparation; they can be used to seed through stands of shrubs. Rangeland drills have single-disk furrow openers followed by chain or pipe drags to cover the seeds. As a consequence furrow depth and the degree to which seeds are covered are highly variable, although depth bands can be attached to control seeding depths. A rangeland drill is available at the equipment pool at the Central Facilities Area, INEL. We recommend that its use be limited to those sites where conditions preclude use of cultipackers or grain drills.

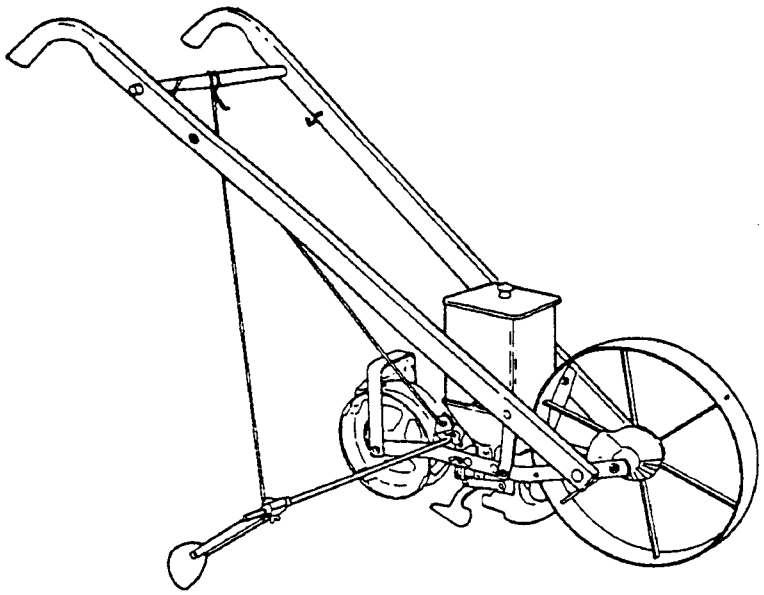
For revegetation projects, it often is desirable to seed a mixture of species, including grasses, forbs, and shrubs. Ideally, seeds of different species, or at least different growth forms, should be planted in separate locations. Most drills are not equipped with multiple boxes for metering seeds that differ markedly in size. Small seeds can be dispersed with the other seeds by using some inert materials such as rice

hulls or vermiculite to increase the volume of the materials seeded (Young and Evans 1987). However, the mixture of seeds is planted together with the same furrow opener, which may result in intense interspecific competition. This can be avoided by partitioning the drill box with cardboard dividers (held in place with duct tape) and placing seeds of different life forms in different sections, using inert material as needed to compensate for small size. (It may not be possible to drill the seeds of some shrubs; see "Broadcast Seeding"). Several new "high technology" drills, developed for revegetation of grazing lands, are available commercially (Young and Evans 1987). These have multiple boxes and corresponding openers so that seeds of different species can be metered and seeded separately. They also provide for accurate planting depths and good seed coverage. Some commercial operators that do custom planting in the region have these drills; names and addresses of such contractors can be obtained by asking the State Office of the Bureau of Land Management for a recent list of revegetation project bidders.

Drill Seeding by Hand or with Tractor-mounted Planters

For small projects, we have found a hand seeder (Planet Jr., Cole Manufacturing Co., Charlotte, N.C. 28299) to be convenient, efficient, and effective. This implement, reminiscent of the garden cultivator, consists of a seed hopper, a wheel that drives the seed metering mechanism, a furrow opener, a furrow closer, a smaller wheel packer, and two wooden handles (Figure 2). For seeding, it is pushed and easily maneuvered by one person. This technique is obviously labor intensive, but for projects up to a few acres in size or for scattered small plots, this approach may be much more economical than using motorized

Figure 2. One-person, ground driven hand seeder (figure from Cole Manufacturing Co. Owner's Manual).



equipment. We have found that one person can easily seed an acre per day using this garden seeder.

Seeders of this type, designed to be mounted on a tool bar, can be drawn with a conventional tractor. Several units can be mounted on a single draw bar. John Deere Flex Planters are the most commonly used units.

Broadcast Seeding

Two situations may necessitate broadcast seeding, which is simply scattering the seed onto the soil surface: 1) A site may be too steep or rocky for tillage and drilling. 2) The size or other characteristics of a particular seed (or fruit) may preclude drilling.

Some shrubs have large seeds that may be difficult to meter through a conventional drill, especially in a mixture with grasses. Others, such as winterfat, have plumed fruits which make drill seeding difficult. At the other extreme we find sagebrush, which has minuscule seeds that are almost impossible to meter through a conventional drill. Broadcast seeding may be the most efficient and effective way to plant such seeds. Seeds for some species, including winterfat, are available in a pelleted form, which may increase survival when broadcast. The pellets deter seed predators and provide nutrients for the seedling.

Broadcast seeding will almost certainly be more effective if it is followed by a treatment with a harrow or cultipacker to cover the seed. If the plan calls for drilling some seeds and broadcasting others, broadcasting should precede drilling or be concurrent with it, with the seed broadcast ahead of the drill. The drilling operation will then help cover the seeds that have been broadcast.

Broadcast seeders range from small, handheld cyclone seeders to centrifugal-type broadcasters that can be hauled in the back of a pickup truck (USDA Forest Service 1979). The centrifugal types have an effective spreading width of about 10 m (30 ft). They can also be used to apply granular and pelleted fertilizers.

A device that has been used effectively to broadcast seeds of shrubs in conjunction with a drilling operation is the seed dribbler. This device is mounted on a tracked vehicle. Seed is dropped onto the vehicle's track which, in turn, drops the seed onto the ground and presses it into the soil. Seed dribblers are available from Laird Welding and Manufacturing Wks., P.O. Box 1053, Merced, CA 95341.

A hydroseeder applies seed by means of a high-pressure stream of water. A mulch may be applied in the same operation or by the same machine after the seed is applied. This technique is used widely for planting steep slopes for mining and highway-construction reclamation projects. It will probably be less effective than drilling or broadcasting followed by harrowing/packing where the terrain permits those practices. Hydroseeding is expensive and often results in poor establishment in dry areas (N. Shaw, personal communication).

Transplanting

Container-grown Stock

Three kinds of plant of materials that commonly are transplanted have application for revegetation projects at the INEL: container-grown stock, bare-root stock, and wildings. Container-grown plants are established in a greenhouse in small pots or tubes containing a potting medium. They are grown in the greenhouse until they reach a certain size and are then transferred to a hardening shelter. Container-grown plants are usually planted by hand. A hole is made with an auger, a planting bar, a mattock, or a "dibble punch" (USDA Forest

Service 1979) to a depth similar to that of the plant container. The plant is carefully removed from the container and placed into the hole, taking care to keep the root plug intact. The soil is then firmed around the plant to eliminate air spaces. Care must be taken to insure that container-grown plants are sufficiently hardened, do not dry out prior to planting, and have an adequate supply of water after planting.

Bare-root Stock

Bare-root stock plants are raised in nurseries and then lifted from their beds while dormant. They are stored and transported with essentially no soil (hence the name), thus large numbers can be shipped at low cost. These plants must be planted before they break dormancy, and care must be taken to insure that the roots do not dry out during storage, transport, or planting. Bare-root stock must be planted into moist soil, and no air spaces should remain around the roots once they are in the soil. A tree planter could be used for planting bare-root stock in areas free of rocks.

Wildings

At the INEL, we have found that for small disturbances, such as construction sites, decommission-decontamination sites, and hazardous waste disposal sites, transplanting wildlings is a convenient and economical method for establishing plant cover (Shumar and Anderson 1987). Wildings are individual plants that are removed from nearby natural communities and immediately transplanted onto a disturbed site (USDA Forest Service 1979). This technique takes advantage of locally-adapted populations and does not introduce new species or foreign genetic material to the area.

In conjunction with a study of evapotranspiration from hazardous-waste disposal areas (Anderson et al. 1987), some 400 basin wildrye, 600 crested wheatgrass, and 400 Wyoming big sagebrush were transplanted. In other studies, we have transplanted 2600 big sagebrush (two subspecies) and 2000 green rabbitbrush plants. In all cases, survival has been better than 85% (Shumar and Anderson 1987). It seems likely that similar results could be obtained with many other native species.

We transplanted wildings in October and November when plants were quiescent, but before the ground was frozen, or in early spring, just after snowmelt. Both bunchgrasses (15-20 cm in basal diameter) and shrubs (15-30 cm tall) were removed from the soil by driving the length of a spade-point shovel into the ground next to the plant and lifting out the plant and a shovel-full of soil. Shrubs were placed into 15-20 cm diameter plastic or metal pots to keep the soil mass intact. Bunchgrasses typically had sufficient root mass to hold the soil in place; thus they usually were moved without use of a container. Plants were taken to the revegetation site and placed in holes large enough to hold the plant and soil transported with it. Some care was required to prevent the soil from falling away from the roots when placing the shrubs into the holes. This was done by holding one hand over the top of the pot, turning the pot over, pulling off the pot, and quickly turning the plant and soil right side up into the hole. The crown and root mass of bunchgrasses may be subdivided to increase the number of transplants.

Transplanting wildings has little impact on the natural communities from which the plants were removed. The density of "natural" stands of crested wheatgrass at the INEL is about 60,000 plants/ha (24,000 plants/acre); that for basin wildrye and green rabbitbrush is about 35,000 plants/ha (14,000 per acre). Sagebrush densities are

somewhat lower, but often exceed 10,000 plants/ha (4,000 per acre). Approximately 10 ha (25 acres) of native vegetation supplied 2000 big sagebrush and 2000 green rabbitbrush plants for one revegetation project at INEL (Shumar and Anderson 1987). Because only small plants (30 cm tall) were moved, no visual impacts on the natural communities were apparent. Gaps created by removal of plants were no larger than those occurring naturally in these communities.

Recommended Seeding/Planting Mixtures

Native Mixtures

Table 3 lists recommended seeding/planting mixtures for those situations where the objective is to restore a diverse community of native species. The composition of natural communities that existed on the site prior to the disturbance, or that on adjacent sites, should serve as a basis for choosing and modifying these general recommendations.

Waste Management Sites and Roadsides

This mixture is recommended for trench caps and other disturbed areas at hazardous-waste burial sites or for roadsides where it is desirable to establish a stable cover of relatively unpalatable perennial grasses that will resist invasion by other species and not attract wildlife.

Species	Seeding Rate (lb/acre)	Method
P-27 Siberian wheatgrass	6	Drill
'Ephraim' Crested wheatgrass	2	Drill
'Sodar' streambank wheatgrass	4	Drill

Greenstripping

Greenstripping refers to the establishment of strips, 30 m (100 ft) or more in width, of fire resistant vegetation for the purpose of reducing the risk and size of wildfires (Gebhardt et al. 1987). Examples include planting fire resistant vegetation adjacent to roadways or railways, around facilities, or around native sagebrush steppe stands that are adjacent to blocks of flash fuels such as cheatgrass.

For greenstrips adjacent to roadways or railways, use the mix suggested above for waste management sites and roadsides.

For fire breaks to protect stands of natural vegetation or to break up large blocks of flash fuels such as cheatgrass, the following mixture is recommended:

Species	Seeding Rate (lb/acre)	Method
P-27 Siberian wheatgrass	8	Drill
'Sodar' streambank wheatgrass	4	Drill
'Delar' small burnet	3	Drill
Lewis flax	2-3	Drill
Alfalfa	2-3	Drill

On deep soils, drainage areas, or areas of sand accumulation, reduce Siberian wheatgrass to 4 #/acre and add 8 #/acre of 'Magnar' basin wildrye.

Table 3. Recommended seeding/planting mixtures for restoring diverse communities of native species. Numbers in parentheses are recommended seeding rates in pounds/acre. Recommended varieties are shown in parentheses below species names. If no released variety exists, local collection is recommended. See "Characteristics of Recommended Species" for additional information. A list of common and scientific names is given in the Appendix.

	Sagebrush Steppe	Winterfat/ Saltbush	Great Basin Wildrye	Threetip Sagebrush	Utah Juniper	Planting Method
Grasses:						
Bluebunch wheatgrass ('Goldar')	2			2	2	Drill, Cultipacker seeder
Thick-spiked wheatgrass ('Critana')	2			1		Drill, Cultipacker seeder
Snake River wheatgrass ('Secar')	1			1		Drill, Cultipacker seeder
Western wheatgrass ('Arriba' or 'Rosana')	1	2		2	2	Drill, Cultipacker seeder
Streambank wheatgrass ('Sodar')	1	1				Drill, Cultipacker seeder
Great Basin wildrye ('Magnar')			2-5	1		Drill, Cultipacker seeder
Indian ricegrass ('Nezpar')	1-2	1-2		1-2	2	Drill, Cultipacker seeder
Bottlebrush squirreltail (Local collection)	1-2	1-2	1	1		Drill, Cultipacker seeder

Forbs:						
Lewis flax ('Appar')	1-2	1-2		1-2	1-2	Drill, Cultipacker seeder
Western hedysarum (Local collection)	1-2	1-2				Drill, Cultipacker seeder
Penstemon ('Bandera')	1-2			1-2	1-2	Drill, Cultipacker seeder
Globe-mallow (Local collection)	1-2			1-2	1-2	Drill, Cultipacker seeder
Shrubs:						
Big sagebrush (Local collection)	0.5-1		0.5-1			Cultipacker seeder Broadcast, Wilding
Threetip sagebrush (Local collection)				0.5-1	0.5-1	Cultipacker seeder
Gray rabbitbrush (Local collection)	0.5-1		0.5-1		0.5-1	
Green rabbitbrush (Local collection)	0.5-1	2		0.5-1	0.5-1	Cultipacker seeder Broadcast, Wilding
Winterfat (Local collection)	0.5-2	2-4				Cultipacker seeder Broadcast, Wilding
Shadscale (Local collection)		2-4				Cultipacker seeder Container or bare-root
Spiny hopsage (Local collection)		2-4				Cultipacker seeder Container or bare-root

1. Rather than seeding, wildings of sagebrush and green rabbitbrush could be transplanted onto the site at low density (e.g., 1 plant of each species per 1000 ft^2). See "Wildings" for more information.

Other species that remain green late in the season and therefore have good potential for greenstripping are 'Bozoisky' Russian wildrye and 'Paiute' orchard grass.

These recommendations are modified from those in Gebhardt, et al. (1987) and Mangan et al. (1987), based on results of species trials at the INEL experimental garden. It is probable that current research by an interagency Greenstripping Task Force will identify additional species and more effective techniques for establishing fire breaks. Additional information on greenstripping can be obtained from the Idaho State Office, Bureau of Land Management, 3380 Americana Terrace, Boise, ID 83706.

WHEN TO PLANT

As a general guideline, the most favorable time for planting is immediately prior to the longest period of conditions favorable for plant growth. At the INEL, the growing season typically begins in early April and extends into June or July, at which time soil moisture reserves are depleted. Because the growing season is preceded by winter months during which most plants are dormant or quiescent, planting can be done in the fall, late winter or early spring.

Seeding

Seeds should be drilled or broadcast in the late fall (mid October through November) or late winter (February, early March). Fall seeding has several advantages. The soils usually are relatively dry, so impacts of heavy equipment are minimized and the seedbed will remain in good condition for plant establishment. Seeds will be in the ground when temperature and moisture conditions are optimal the following spring. Some seeds require a cold treatment for germination; fall seeding insures that seeds are exposed to such conditions.

At the INEL, there is some risk of seeding failure associated with fall seeding. The area often experiences a warming period in February followed by another cold period before favorable temperatures arrive in the spring. Seedlings that emerge during this warm period in February may be killed by desiccation or freezing during the subsequent cold period. Seeding during the warm period in February or early March will preclude this problem. Seeds will receive some cold treatment and be in the soil and ready to germinate when temperature and moisture conditions are favorable in the spring. The risk here is that wet soil conditions may preclude the use of heavy equipment or result in undesirable rutting and/or compaction of the seedbed. It is also improbable that a period suitable for late-winter seeding will occur every year. But when conditions are suitable, this is an ideal time to seed at the INEL.

Container-grown Plants and Bare-root Stock

Container-grown and bare-root plants should be transplanted in the early spring (late March, April), normally as soon as possible after the soil has thawed and snow has melted. Ideally, the plants should be transplanted before they have broken dormancy. If spring moisture is limited, planting may be delayed until early May, but in such cases, supplemental irrigation may be required to insure establishment.

Wildings

Wildings can be transplanted in late fall (mid October through November or later if soils remain unfrozen) or late winter/early spring before the plants break dormancy.

WHAT TO EXPECT -- EVALUATION OF SUCCESS

Cover of perennial species is probably the best quantitative measure for evaluating the success of reclamation plantings, although the visual aspect of the area may suffice for many projects. Cover can be measured conveniently using the point interception frame described by Floyd and Anderson (1982). Total plant cover of the natural vegetation at the INEL is about 25% (Anderson and Inouye 1988). Total basal cover of crested wheatgrass in seeded stands at the INEL is typically about 39% (Anderson and Marlette 1986).

A thorough discussion of techniques for estimating and evaluating plant species diversity in revegetation projects was provided by Chambers (1983). Various diversity indices can be calculated from cover data.

In arid regions, vegetation development can be very slow, especially during periods of drought. Often, several growing seasons after the initial planting may be necessary to achieve the reclamation objectives. Grasses such as crested or streambank wheatgrass that have vigorous, drought-tolerant seedlings will usually establish a good stand during the first growing season, but these plantings will not look like a lawn or a grain field! Establishment of viable populations of shrubs and many native grasses and forbs from seed may take several growing seasons.

In the fall of 1982, we seeded a 5 acre plot near the INEL Experimental Field Station as a demonstration reclamation project. This plot in native sagebrush steppe was disked, tilled with a "rotovator", packed, and drilled with a rangeland drill. Three different mixtures of native grasses, forbs, and shrubs were planted on different sections of the plot. At the end of the first growing season, the project appeared to be a complete failure. Grass and forb seedlings were apparent, but they were present in very low densities. Weeds were abundant on the plot during the second growing season. However, the seeded species began to take over during the third season, and by the end of the fourth year a diverse stand of perennial grasses and shrubs had developed, and weedy species were uncommon. Cover of perennial species in the fourth growing season was 20%, comparable to the 23% recorded in the adjacent natural vegetation.

Prolonged spring drought after seeds have germinated or a lack of winter snowpack to recharge soil moisture may spell failure for a seeding project. Such a situation will be evidenced by very low densities or absence of seedlings of seeded species by mid summer. In these cases, reseeding during the following fall or spring may be necessary.

LITERATURE CITED

Anderson, J.E. 1986. Development and structure of sagebrush steppe plant communities. pp. 10-12 in Rangelands: A Resource Under Siege, P.J. Joss, P.W. Lynch, and O.B. Williams, eds. Proceedings of the Second International Rangeland Congress. Australian Academy of Science, Canberra.

Anderson, J.E. and R. Inouye. 1988. Long-term dynamics of vegetation in a sagebrush steppe of southeastern Idaho. Final Report, Subcontract C84-110421, Ecological Studies Program, Idaho National Engineering Laboratory. 54 p.

Anderson, J.E. and G.M. Marlette. 1986. Probabilities of seedling recruitment and the stability of crested wheatgrass stands. pp. 97- 105 in Crested Wheatgrass: Its Values, Problems, and Myths, K.L. Johnson, ed. Symposium Proceedings, Utah State University, Logan.

Anderson, J.E., M.L. Shumar, N.L. Toft, and R.S. Nowak. 1987. Control of the soil water balance by sagebrush and three perennial grasses in a cold-desert environment. Arid Soil Research and Rehabilitation 1:229- 244.

Arthur, W.J. and O.D. Markham. 1983. Small mammal soil burrowing as a radionuclide transport vector at a radioactive waste disposal area in southeastern Idaho. Journal of Environmental Quality 12:117-122.

Asay, K.H. 1983. Promising new grasses for range seedings. pp. 110-114 in Managing Intermountain Rangelands -- Improvement of Range and Wildlife Habitats, S.B. Monsen and N. Shaw, compilers. USDA Forest Service General Technical Report INT-157. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Bunting, S.C., B.M. Kilgore, and C.L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. USDA Forest Service General Technical Report INT-231. Intermountain Research Station, Ogden, UT. 33 p.

Caldwell, M. 1985. Cold desert, pp. 198-212, in: B.F. Chabot and H.A. Mooney, eds., Physiological Ecology of North American Plant Communities. Chapman and Hall, New York.

Chambers, J.C. 1983. Measuring species diversity on revegetated surface mines: an evaluation of techniques. USDA Forest Service Research Paper INT-322. Intermountain Forest and Range Experiment Station, Ogden, Utah. 15 p.

Cholewa, A.F. and D.M. Henderson. 1984. A survey and assessment of the rare vascular plants of the Idaho National Engineering Laboratory DOE/ID-12100, National Technical Information Service, Springfield, VA. 45 pp.

Daubenmire, R. 1970. Steppe vegetation of Washington. Washington Agriculture Experiment Station Technical Bulletin 62. 131 p.

Dealy, J.E., D.A. Leckenby, and D.M. Concannon. 1981. Wildlife habitats in managed rangelands -- the Great Basin of Southeastern Oregon. USDA Forest Service General Technical Report PNW-120. Pacific Northwest Forest and Range Experiment Station. 66 p.

Eissenstat, D.M. and M.M. Caldwell. 1988. Competitive ability is linked to rates of water extraction. A field study of two aridland tussock grasses. Oecologia 75:1-7.

Floyd, D.A. 1982. A comparison of three methods for estimating vegetal cover in sagebrush steppe communities. M.S. Thesis, Idaho State University, Pocatello.

Floyd, D.A. and J.E. Anderson. 1982. A new point interception frame for estimating cover of vegetation. Vegetatio 50:185-186.

French, N.R. and J.E. Mitchell. 1983. Long-term vegetation changes in permanent quadrats at the Idaho National Engineering Laboratory Site. Bulletin No. 36, Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow. 42 p.

Gebhardt, K., M. Boltz, S. Frazier, L. Mangan, M. Miller, M. Pellant, R. Rosentreter, and J. Taylor. 1987. Greenstripping handbook. Idaho State Office, Bureau of Land Management.

Groves, C.R. and B.L. Keller. 1983. Ecological characteristics of small mammals on a radioactive waste disposal area in southeastern Idaho. American Midland Naturalist 109:253-265.

Harniss, R.O. and N.E. West. 1973. Vegetation patterns on the National Reactor Testing Station, southeastern Idaho. Northwest Science 47:30-43.

Heinrichs, D.H. and Bolton, J.L. 1950. Studies on the competition of crested wheatgrass with perennial native species. Scientific Agriculture 30:428-443.

Hingtgen, T.M. and W.R. Clark. 1984. Small mammal recolonization of reclaimed coal surface-mined land in Wyoming. Journal of Wildlife Management 48:1255-1261.

Hitchcock, C.L. and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle.

Hull, A.C., Jr. and G.J. Klomp. 1966. Longevity of crested wheatgrass in the sagebrush-grass type in southern Idaho. Journal of Range Management 19:5-11.

Jeppson, R.J. and K.E. Holte. 1978. Flora of the Idaho National Engineering Laboratory Site. pp.

129-143 in Ecological Studies on the Idaho National Engineering Laboratory Site, 1978 Progress Report, O.D. Markham, ed. U.S. Department of Energy, Idaho Operations Office, Idaho Falls.

Keller, W. and A.T. Bleak. 1974. Kochia prostrata: a shrub for western ranges? Utah Science 35:24-25.

Klemmedson, J.O. and J.G. Smith. 1964. Cheatgrass (Bromus tectorum L.). Botanical Review 30:226-262.

Laundré, J.W. 1986. Effect of Townsend ground squirrel burrows on infiltration of soil water in semi-arid environments. Abstract #139 in Abstracts, American Society of Mammalogists, 66th Annual Meeting. Zoological Museum, University of Wisconsin-Madison.

Lesperance, A.L., J.A. Young, R.E. Eckert, Jr. and R.E. Evans. 1978. Great Basin wildrye. Rangeman's Journal 5:125-127.

Looman, J. and D.H. Heinrichs. 1973. Stability of crested wheatgrass pastures under long-term pasture use. Canadian Journal of Plant Science 53:501-506.

Lyon, L.J. and P.F. Stickney. 1976. Early vegetal succession following large northern Rocky Mountain wildfires. Proceedings Montana Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium 14:355-375.

Mangan, L., C. Ogden, and C. Kvale. 1987. Wildhorse greenstripping/ shrub restoration plan. Idaho Cooperative Shrub Restoration Program. Idaho Fish and Game and Bureau of Land Management. 46 p.

Marlette, G.M. and J.E. Anderson. 1986. Seed banks and propagule dispersal in crested-wheatgrass stands. Journal of Applied Ecology23:161- 175.

McArthur, E.D., A.P. Plummer, and J.N. Davis. 1978. Rehabilitation of game range in the salt desert. pp. 23-50 in Wyoming Shrublands, Proceedings of the Seventh Wyoming Shrub Ecology Workshop. Range Management Division, University of Wyoming, Laramie.

McBride, R., N.R. French, A.H. Dahl, and J.E. Detmer. 1978. Vegetation types and surface soils of the Idaho National Engineering Laboratory Site. IDO-12084. National Technical Information Service, Springfield, Virginia. 29 p.

Monsen, S.B. and N. Shaw. 1983. Managing Intermountain Rangelands -- Improvement of Range and Wildlife Habitats. USDA Forest Service General Technical Report INT-157. Intermountain Forest and Range Experiment Station, Ogden, Utah. 194 pp.

Morin-Jansen, A. 1987. A study of the principal lineament and associated lineaments, Idaho National Engineering Laboratory. M.S. Thesis, Idaho State University, Pocatello. 79 p.

Morrow, L.A. and P.W. Stahlman. 1984. The history and distribution of downy brome (Bromus tectorum) in North America. Weed Science 32, Supplement 1:2-6.

Parmenter, R.R., J.A. MacMahon, M.E. Waaland, M.M. Stuebe, P. Landres, and C.M. Crisafulli. 1985. Reclamation of surface coal mines in western Wyoming for wildlife habitat: a preliminary analysis. Reclamation and Revegetation Research 4:93-115.

Perry, L.J., Jr. and S.R. Chapman. 1975. Effects of clipping on dry matter yields of basin wildrye. Journal of Range Management 28:271-274.

Reynolds, T.D. and C.H. Trost. 1980. The response of native vertebrate populations to crested wheatgrass planting and grazing by sheep. Journal of Range Management 33:122-125.

Rogler, G.A. and R.J. Lorenz. 1983. Crested wheatgrass -- early history in the United States. Journal of Range Management 36:91-93.

Rumbaugh, M.D. 1983. Legumes -- their use in wildland plantings. pp. 115-122 in Managing Intermountain Rangelends -- Improvement of Range and Wildlife Habitats, S.B. Monsen and N. Shaw, compilers. USDA Forest Service General Technical Report INT-157. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Schuman, G.E., F. Rauze, and D.T. Booth. 1982. Production and competition of crested wheatgrass-native grass mixtures. Agronomy Journal 74:23-26.

Sharp, L.A. and W.F. Barr. 1960. Preliminary investigations of harvester ants on southern Idaho ran-

gelands. Journal of Range Management 13:131-134.

Shaw, N. and S.B. Monsen. 1983. Nonleguminous forbs for rangeland sites. pp. 123-131 in Managing Intermountain Rangelends -- Improvement of Range and Wildlife Habitats, S.B. Monsen and N. Shaw, compilers. USDA Forest Service General Technical Report INT-157. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Shumar, M.L. and J.E. Anderson. 1986a. Gradient analysis of vegetation dominated by two subspecies of big sagebrush. Journal of Range Management 39:156-160.

Shumar, M.L. and J.E. Anderson. 1986b. Water relations of two subspecies of big sagebrush on sand dunes in southeastern Idaho. Northwest Science 60:179-185.

Shumar, M.L. and J.E. Anderson. 1987. Transplanting wildings in small revegetation projects. Arid Soil Research and Rehabilitation 1:253- 256.

Shumar, M.L., J.E. Anderson, and T.D. Reynolds. 1982. Identification of subspecies of big sagebrush by ultraviolet spectrophotometry. Journal of Range Management 35:60-62.

Sneva, F.A. 1979. The western harvester ants: their density and hill size in relation to herbaceous productivity and big sagebrush cover. Journal of Range Management 32:46-47.

Sours, J.M. 1983. Characteristics and uses of important grasses for arid western rangelands. pp. 90-94 in Managing Intermountain Rangelands -- Improvement of Range and Wildlife Habitats, S.B. Monsen and N. Shaw, compilers. USDA Forest Service General Technical Report INT-157. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Stevens, R., K.R. Jorgensen, E.D. McArthur, and J.N. Davis. 1985. 'Immigrant' forage kochia. Rangelands 7:22-23.

Stevens, R. and S.B. Monsen. 1985. 'Ephraim' crested wheatgrass - a rhizomatous grass for western ranges and disturbed sites. Rangelands 7:163-164.

Stevens, R. and S.B. Monsen. 1988a. 'Cedar' Palmer penstemon: a selected penstemon for semiarid ranges. Rangelands 10:163-164.

Stevens, R. and S.B. Monsen. 1988b. 'Hatch' winterfat: a quality shrub for ranges and wildlands. Rangelands 10:104-105.

Tomlinson, P. 1984. Evaluating the success of land reclamation schemes. Landscape Planning 11:187-203.

USDA Forest Service. 1979. User guide to vegetation -- mining and reclamation in the West. General Technical Report INT-64. Intermountain Forest and Range Experiment Station, Ogden, Utah. 85 pp.

Vallentine, J.F. 1971. Range development and improvements. Brigham Young University Press, Provo, Utah. 516 pp.

West, N.E. 1983. Western intermountain sagebrush steppe. pp. 351- 374 in Temperate Deserts and Semi-deserts, N. E. West, ed. Elsevier Scientific Publishing Company, New York.

Wright, H.A. and A.W. Bailey. 1982. Fire Ecology. John Wiley and Sons, New York. 501 pp.

Young, J.A. and R.A. Evans. 1973. Downy brome - - intruder in the plant succession of big sagebrush communities in the Great Basin. Journal of Range Management 26:410-415.

Young, J.A. and R.A. Evans. 1986. Early use of crested wheatgrass in the Intermountain area, pp. 21-25, in: K.L. Johnson, ed., Crested Wheatgrass: Its Values, Problems and Myths; Symposium Proceedings. Utah State University, Logan.

Young, J.A. and R.A. Evans. 1987. Technology for seeding on sagebrush rangelands. pp. 15-18 in Integrated Pest Management on Rangeland: State of the Art in the Sagebrush Ecosystem, J.A. Onsager, ed. USDA Agricultural Research Service ARS-50. National Technical Information Service, Springfield, Virginia.

APPENDIX - INDEX TO SCIENTIFIC AND COMMON NAMES

Oryzopsis hymenoides ..... Indian ricegrass 2, 4, 3, 14, 18, 28
Poa nevadensis ..... Nevada bluegrass 3, 5
Poa sandbergii ..... Sandberg's bluegrass 3, 5
Poa scabrella ..... Canby bluegrass 14
Sitanion hystrix ..... Bottlebrush squirreltail 2, 3, 4, 28
Stipa comata ..... Needle-and-thread 2, 3

Forbs and Succulents

Arabis spp. ..... Rockcress 3
Astragalus ceramicus ..... Painted milk-vetch 5
Astragalus cicer ..... Cicer milk-vetch 15
Astragalus gilviflorus ..... Plains orophaca 5
Astragalus kentrophyta ..... Thistle milk-vetch 5
Camissonia pterosperma ..... none 5
Castelleja angustifolia ..... Indian paintbrush 3
Chaenactis douglasii ..... False-yarrow 3
Comandra umbellata ..... Bastard toad-flax 3
Coryphantha missouriensis ... Pin-cushion or nipple cactus 5
Crepis acuminata ..... Tapertip hawksbeard 3
Erigeron pumilus ..... Shaggy fleabane 3
Gilia polycladon ..... none 5
Gymnosteris nudicaulis ..... Large-flowered gymnosteris 5
Hedysarum boreale ..... Western hedysarum 3, 4, 15, 19, 29
Lesquerella kingii ..... King's bladderpod 5
Linum perenne ..... Lewis flax 15, 18, 27, 29
Lomatium triternatum ..... Nine-leaf desert-parsley 3
Medicago sativa ..... Alfalfa 27
Opuntia polyacantha ..... Prickly-pear cactus 3
Oxytheca dendroidea ..... none 5
Penstemon palmeri ..... Palmer penstemon 15, 18, 29
Penstemon strictus ..... Rocky Mountain penstemon 15, 18
Phlox hoodii ..... Hood's phlox 3
Phlox longifolia ..... Long-leaf phlox 3
Sanguisorba minor ..... Small burne 15, 19, 27
Sphaeralcea munroana ..... Munro's globe-mallow 3, 29
Stanleya viridiflora ..... Princesplume 3